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Private Investment in Agricultural Research and International Technology Transfer in Asia

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About the Authors

Much of this work was done while Keith Fuglie was employed by the Economic Research Service and while Carl Pray was on sabbatical leave with the Economic Research Service.

Abstract

This study addresses the questions of future sources of technology for increasing food and agricultural production by considering the situation in Asia. This region of the world is particularly appropriate for studying these questions because of the dynamic changes in population and incomes. How much private research is there and what is it producing? Will the private sector compensate for declining public agricultural research investments in Asia? What can governments do to stimulate private research and protect farmers from harmful or defective technology? Agribusiness firm's R&D investments were evaluated in selected developing countries during 1996 and 1998 and compared with data from a similar study conducted in the mid-1980s. The largest amount of private research was in India where investment was about $55 million per year in the mid-1990s, followed by Thailand, Malaysia, and China. China's private R&D spending represents less than one one-hundredth of 1 percent of agricultural gross domestic product. In contrast, in Thailand and Malaysia, firms spent about 0.1 percent. From the mid-1980s to the mid-1990s, private sector R&D grew in real terms in the countries in our sample. However, at this rate, private research will not fill the gap needed to support rapid growth in demand for agricultural products. Foreign firms made an important contribution to private research in all of these countries. The most important policy that helped induce this growth was liberalization of industrial policy that allowed private and foreign firms to operate and expand in agricultural input industries. A second important policy was investments in public research. Patents and tax incentives seem to have had little effect so far, but could be important in the future.

Keywords: Agricultural research and development (R&D), private sector R&D, technology transfer, Asian R&D.

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Contents

Chapter 2—Pakistan

Chapter 3—Thailand

Chapter 4—Indonesia

Chapter 5—Malaysia

Executive Summary

Research Problem

A consensus has developed that technology will be required to provide the major source of growth in Asian agriculture in the 21st century. Public financing of agricultural research seems to be declining in developing countries. The question is whether private research and technology transfer will fill that gap. The answer to that question is important to U.S. farmers because Asia is now the most important market for U.S. agricultural exports and is likely to be much more important in the future.

This report presents an overview of trends in private research investment and a summary of findings from country case studies.

Research Methods and Sources of Data

The countries we studied are India, Pakistan, Thailand, Indonesia, Malaysia, the Philippines, and China. The first six were chosen because they had been the subject of an earlier study by Pray in the mid-1980s. China was added because of its size and importance.

We collected the data on research and development (R&D) through personal interviews at key firms and from government statistics. The authors visited each country and participated in the surveys, except in Pakistan where we commissioned Nagy and Ahmad to conduct the survey.

Stylized Facts about Private Agricultural Research in Asia

The largest amount of private research was in India where investment totaled about $55 million per year in the mid-1990s. The next largest amounts of private research expenditure were in Thailand, Malaysia, and China.

Relative to the size of its agricultural economy, investment in private research in China was particularly small—less than 0.01 percent of agricultural gross domestic product (GDP). In contrast, in Thailand and Malaysia, firms spent about 0.1 percent.

Between 1985-87 and 1995-98, private sector R&D grew in real terms in all countries in our sample. In India, Pakistan, Indonesia, and China, research funding more than doubled in 10 years. Even at this rate, however, private research will not fill the gap needed to support rapid growth in demand for agricultural products.

The agricultural chemical industry conducted the most private research, followed by the agricultural processing and plantation industries.

Foreign firms made an important contribution to private research in all of these countries. At one extreme is China in which almost all private research was by joint ventures between foreign and local firms. Malaysia is at the other extreme with little research by foreign firms. In Pakistan and India, foreign-owned firms conducted about a third of the research.

Causes of Patterns of Research Expenditure

Growth in Demand

There is a positive relationship between growth of private agricultural research and growth in demand for agriculture as measured by agricultural GDP. Research and production were growing at roughly the same rate from the mid-1980s to the mid-1990s in Thailand, Malaysia, and the Philippines. In India, Pakistan, Indonesia, and China, private research grew even more rapidly than agricultural production.

Impact of Growth in the International Supply of Technology

The slowdown in growth in demand for agricultural inputs in the United States, Europe, and Japan made Asian markets very attractive relative to U.S. firms. Foreign firms accounted for much of the growth in private research in Asia. They accounted for about half of all private research in these countries and were concentrated in the industries where private agricultural R&D has been growing most rapidly—chemicals, livestock, and seed.

Market Liberalization and Competition Policy

The major policy changes that stimulated more private research in Asia were eliminating public sector monopolies, reducing subsidies for public sector input firms, and allowing foreign firms to play a larger role in input industries. The most liberal market economies in the mid-1980s—Thailand, Malaysia, and the Philippines—had the highest private research intensities. The countries with the most controlled economies—China, Indonesia, Pakistan, and India—had the lowest private research intensities. The countries in which private research intensity grew most rapidly—China, India, Pakistan, and Indonesia—had major liberalization programs during this period. China and India still have important barriers to the importation of agricultural inputs, and China severely restricts foreign investment.

Public Research

There is evidence of strong complementarities between public and private agricultural research in Asia. Public investment in agricultural science was one of the principal sources of new technological opportunities for applied R&D. Public research provided basic technology such as downy mildew-resistant corn in Southeast Asia and downy mildew-resistant pearl millet. Public research has also been very important as a source of scientists for private research.

Intellectual Property Rights

Although legal protection of intellectual property has been strengthened in several countries, its enforcement remains weak. Thus, intellectual property rights have played a limited role in stimulating the growth of research. Input firms primarily used technical means of protecting their intellectual property. Seed companies protected new plant varieties by producing hybrids. Chemical companies protected new pesticides or pharmaceuticals by keeping the process of production secret and by making chemicals that are difficult to reproduce. Plantations captured benefits of research by developing technology that can be used only on their own plantations.

Encouraging Private Research in Asian Countries

To encourage private investment in research, Asian governments might consider the following strategies:

1. Continuing liberalization of economies, particularly agricultural input industries.
2. Strengthening intellectual property rights.
3. Continuing to support public research to complement private research—national, provincial, and international.
4. Developing transparent regulations that are based on local concerns and science.

Policy Implications for the United States

Agricultural development in Asian developing countries has benefited U.S. farmers by creating more demand for their goods and for U.S. food and input firms that invest and export to Asia. Thus, the United States can benefit from rapid economic development through the private sector. Policies that encourage economic development consist of:

1. In the World Trade Organization and in bilateral trade discussions, the U.S. Government could benefit by emphasizing reduced barriers on agricultural input trade and foreign investment in agricultural input industries, because this could have particularly high payoffs in Asian agriculture.
2. Continued U.S. support to the International Agricultural Research Centers is valuable because the centers have provided much of the science and many of the scientists, which are the basis of private research in Asia.
3. Enhancing public research in Asia with additional funds and resources could help draw the attention of private biotechnology firms to developing-country opportunities in food and agriculture.
4. Research opportunities can be expanded through collaborative efforts between USDA's Agricultural Research Service, land-grant universities, and the international agricultural research centers.

Introduction to Private Sector Agricultural Research in Asia

Carl E. Pray and Keith Fuglie

This chapter provides data on the amount of private research, trends in funding, and sources of private research funds and discusses some of the effects of that research.

Methodology for the Country Case Studies

To better understand the significance of the private sector in international agricultural research and technology transfer, we conducted a survey of agribusiness firms in selected developing countries during 1996 and 1998. In addition, we conducted interviews with several multinational agricultural input companies based in the United States and Europe. The goals of the surveys were to:

- determine how much and what kind of agricultural research is conducted by the private sector,
- identify policy constraints and incentives to private research and technology transfer, and
- assess major impacts of these private investments on agricultural productivity.

For the survey, we selected seven countries in Asia: China, India, Indonesia, Malaysia, Pakistan, the Philippines, and Thailand. These countries were selected for several reasons. First, together they represent a broad range of developing countries: two are large developing economies (China and India), two are middle-income, mid-size economies (Malaysia and Thailand), and three are low-income, mid-size economies (Indonesia, Pakistan, and the Philippines). Second, an earlier study conducted a survey on the same set of issues in these countries in 1985 (Pray, 1985 and 1987; and Pray and Echeverria, 1991). As the survey design parallels this earlier work, the present survey enables us to compare results across time. Finally, there has been little recent work on private agricultural research in Asia. Recent studies by Falconi (1992 and 1993) and Echeverria, Trigo, and Byerlee (1996) provide estimates of private agricultural research for several Latin American countries. Little private research is thought to take place in Africa (Thirtle and Echeverria, 1994), with the exception of South Africa and possibly Egypt. Thus, this study helps to fill an important gap in private agricultural research in developing countries.

For each country case study, we conducted personal interviews with managers from the principal seed, livestock, agricultural chemical, farm machinery, biotechnology, and plantation companies in those countries. A mail questionnaire was used when an interview could not be scheduled due to time conflicts. In India and Pakistan, mail questionnaires were used more extensively than in the other countries to reach a large number of companies. In addition, interviews were conducted with government officials from agricultural and science ministries and knowledgeable individuals from universities, research institutes, and foreign aid agencies. However, the personal interviews were conducted in a semi-structured interview format and the list of questions served only as a general guide. This allowed specific issues to be explored in greater depth according to the knowledge and interest of the respondent. The individual country case studies contain more details on the survey design for that country.

Overview of Asian Economies and Agriculture Since 1980

The period from 1980 to 1997 was a prosperous one for most countries in Asia. Per capita incomes and some characteristics of agriculture of the countries in this study are shown in table A-1. Per capita income grew very rapidly in East and Southeast Asia (last column in table A-1) with the exception of the Philippines. Income grew, but less rapidly than in Southeast

Table A-1—Economic and agricultural indicators in selected Asian countries, 1980-95

Country	Agriculture value added	Growth of agriculture value added		Value of agricultural exports	Per capita income	Growth of per capita income
	1995	1980-90	1990-95	1995	1995	1985-95
	Million U.S. dollars	*---Percent---*		*Million U.S. dollars*	*U.S. dollars*	*Percent*
Large, low-income:						
China	146,506	5.9	4.3	14,363	620	8.3
India	93,984	3.1	3.1	5,494	340	3.2
Middle-income:						
Malaysia	11,090	3.8	2.6	8,228	3,890	5.7
Thailand	18,376	4.0	3.1	9,022	2,740	8.4
Mid-size, low-income:						
Indonesia	33,673	3.4	2.9	5,493	980	6.0
Philippines	16,320	1.0	1.6	1,881	1,050	1.5
Pakistan	15,769	4.3	3.4	1,018	460	1.2

Sources: All data from World Bank *World Development Report*, 1997, using PPP exchange rates, except ag export data from the Food and Agriculture Organization of the United Nations' statistical databases.

Asia, in India and Pakistan. The Asian crisis that started in 1997 and was particularly disastrous in Southeast Asia is excluded from this study because we had completed our case studies of Thailand, the Philippines, Indonesia, and Malaysia before the crisis struck.

Agriculture did quite well during this period. All countries except the Philippines had annual growth rates of about 3 percent or more. China, which was going through a massive restructuring of its economy, grew most rapidly. This rapid growth was faster than increases in population and allowed most countries to keep up with increased demand for agricultural products. Most of the growth in these countries can be attributed to increases in yield per unit of land. The increase in crop yields was a function of new plant varieties, developed primarily by public plant-breeding institutes, and increased use of fertilizer and irrigation. Growth in animal productivity was attributable to the combination of new breeds of poultry and swine, developed primarily by the private sector and new feed, health, and commercial management practices, also developed by private firms.

Private Agricultural Research in Asia

The largest amount of private research was in India, where investment was about $55 million per year in the mid-1990s (table A-2). The next largest amounts of private research expenditure were Thailand, Malaysia, and China. The private sector in each of these countries spent $15 to $20 million per year for agricultural research. They were followed by the Philippines, with about $10 million, and Indonesia and Pakistan, with about $6 million. The last column of the table shows the research investment relative to the size of the country's agricultural economy. China's investment in private research was particularly small, spending less than 0.01 percent of agricultural GDP on private research. In contrast, Thailand and Malaysia spent about 0.1 percent. The other countries fall somewhere in between.[1]

Between 1985-87 and 1995-98, private R&D grew in real terms in all of the countries in our sample (table A-2). In India, Pakistan, Indonesia, and China, research funding more than doubled within 10 years. In the Philippines and Thailand, research funding grew between 60 and 70 percent. Malaysia, which had the highest research intensity in both periods, had the smallest increase in growth. Table A-2 shows a clear inverse relationship between research intensity in the 1980s and growth in research expenditure since then.

[1]Some of the differences in levels of research between countries are due to the differences in how state-owned enterprises (SOEs) are handled. SOEs conduct a substantial amount of research in China, India, and Malaysia. This research is included in the private research data in India and Malaysia but China's data were unavailable. In India, SOEs account for 18 percent of the private research— mainly in fertilizers. In Malaysia, government-owned plantations accounted for about 23 percent of private research.

Table A-2—Private agricultural R&D expenditures, growth, and research intensity, Asia, 1985 and 1995

Country	Private R&D expenditures		Increase in private R&D,	Private research intensity (private R&D as percent of agriculture value added)	
	1985-87	1995-98	1988-89	1985-87	1995-98
	Million 1995 ---U.S. dollars[1]---		*---------------------Percent------------------*		
Large, low-income:					
China	0.0	11-16.0	Infinite	0.000	0.009
India	25.7	55.5	116	0.026	0.059
Middle-income:					
Malaysia	14.1	16.6	19	0.173	0.150
Thailand	10.6	17.4	64	0.124	0.095
Mid-size, low-income:					
Indonesia	2.8	6.1	118	0.010	0.018
Philippines	6.2	10.5	69	0.059	0.064
Pakistan	2.4	5.7	138	0.019	0.036
Total	61.8	122.8-127.8	99-107		

[1]Inflated to 1995 prices, using U.S. implicit Gross Domestic Product deflator.

Sources: Expenditures from 1985 Asian countries from Pray and Echeverria, 1991, and 1995-97 author's survey. Research intensity was calculated using agricultural GDP data from World Bank, World Development Report, Washington, DC,. 1987 and 1997.

Table A-3 indicates the importance of private agricultural research relative to all agricultural research in 1995. China again stands out for having only 3 percent of its research conducted by the private sector. The private sector had the highest share in both Malaysia and the Philippines—each over 20 percent. The other countries had between 10 and 20 percent in the private sector.

The agricultural chemical industry conducted the most private research followed by processing and plantation industries. We lumped together processing and plantation industries, because many plantations also conduct research on processing and many processors finance research on agriculture (e.g., breweries support barley variety selection and breeding). Research by the agricultural chemical industry—primarily for plant protection chemicals but also for fertilizer use and biotechnology—experienced the most rapid growth, tripling in real terms between 1985 and 1995 (table A-4). Private livestock research grew almost as rapidly. Private research doubled in other input industries and in the plantation and processing sector.

Foreign firms made an important contribution to private research in all of these countries in 1995 (table A-5). At one extreme was China in which almost all private research was by joint ventures between foreign and local firms. Malaysia was at the other extreme, with little research by foreign firms. In Pakistan and India, foreign-owned firms conducted about a third of the research. In Southeast Asia, seed and pesticide research was done primarily by foreign multinational corporations. The foreign share of the plantation research was determined by government rules on foreign investment. In the Philippines and Thailand, foreign firms were allowed to operate plantations. In Malaysia and Indonesia, foreign plantations owners were gradually bought out (Malaysia) or nationalized (Indonesia). As a result, Malaysia and Indonesia did not have much research by foreign firms related to plantations. For all seven countries, the pesticide industry had the largest share of research. About 40 percent of the research of the seed and livestock industries was conducted by foreign firms. The other industries had a very small percentage of their research funded by foreign firms.

Declining barriers to trade are opening the way for more regional research as multinational companies research for a particular agro-climatic region in the country in which research is the least expensive to do and best protected from copying. The companies then export the technology to other countries in the region. For example, seed companies were moving most of their Southeast Asian corn research to Thailand and had planned to export their varieties from Thailand to other countries. Charoen Pokphand (a Thai agribusi-

Table A-3—Private and public research and research intensity, Asia,1995

Country	Private R&D	Public R&D	Private R&D intensity[2]	Public R&D intensity[2]
	Million 1995	*------U.S. dollars[1]------*	*------Percent------*	
Large, low-income:				
China	16.0 (3)[3]	479.5	0.009	0.327
India	55.5 (14)	347.9	0.059	0.370
Middle-income:				
Malaysia	16.6 (21)	64.0	0.150	0.577
Thailand	17.4 (12)	127.0	0.095	0.691
Mid-size, low-income:				
Indonesia	6.1 (12)	81.0	0.018	0.241
Pakistan	5.7 (19)	25.0	0.036	0.159
Philippines	10.5 (22)	37.5	0.064	0.230
Total	127.8 (11)	1,125.3		

[1]Calculated using official exchange rates.
[2]R&D intensity = R&D as percent of agricultural value added.
[3]Numbers in parentheses show private R&D as a percent of total agricultural R&D.
Sources: See country case studies.

Table A-4–Growth of private R&D, by industry, Asia, 1985 and 1995

Item	1985	1995[1]	Growth
	Million 1995	*-------U.S. Dollars------*	*Percent*
Agricultural machinery	3.9	7.5	92
Agricultural chemicals	14.5	47.0	223
Livestock/animal health	5.4	15.9	193
Plant breeding	8.2	16.4	100
Plantations and processing	21.2	40.8	93
Total	53.2	127.5	140

[1]For 1985 data, see sections for country case studies.

Sources: 1985 surveys by Pray (1985) and Pray (1987).

Table A-5—Research expenditures and share of foreign firms, Asia, 1995

Country	Private R&D	Foreign firms' R&D	Foreign as percent of total private R&D
	Million 1995	*---U.S. dollars[1]---*	*Percent*
Large, low-income:			
China	16.0	16.0	100
India	55.5	16.8	30
Middle-income:			
Malaysia	16.6	1.6	10
Thailand	17.4	11.0	63
Mid-size, low-income:			
Indonesia	6.1	3.5	58
Pakistan	5.7	1.8	31
Philippines	10.5	7.3	69
Total	127.8	58.0	45

[1]Calculated using official exchange rates.
Source: Country case studies.

ness conglomerate) is doing poultry research in China and exporting improved breeds to Thailand.

Another measure of the importance of foreign versus local research in providing technology is patent data. Table A-6 shows the total number of patents in industries that produced agricultural inputs and the percentage of patents owned by local individuals or organizations rather than foreign individuals and organizations in 1987-95. All of these countries are importers of technology, but the largest countries—India and China—by the early 1990s were producing between one-third to one-half of their own inventions as measured by share of patents going to domestic inventors. In contrast, the middle-income countries represented by Malaysia (latest available data is for 1987) and smaller, low-income countries produce few patentable inventions domestically and rely primarily on imported foreign technology. The percentage of local patents is inversely related to the percentage of research by foreign firms in table A-5—except in the case of China where foreigners do almost all of the private research, yet Chinese inventors have more than half of the patents.

These tables show three distinct patterns. The first pattern is represented by China, a country with a mixed socialist and market economy. It has low private research expenditure and very low private research intensity; private research was a small share of total public and private research. But private research is growing very rapidly. A second pattern is observable in the middle-income countries, such as Malaysia and Thailand. They are major exporters of agricultural products in raw or processed form. They spent a relatively high share of agricultural GDP on both public and private research. However, private research expenditure was growing more slowly than in some other countries in the sample, with private research intensity declining: that is, private research has not kept up with the rapid growth in agricultural output. The third pattern is found in the low-income countries other than China—India, Pakistan, the Philippines, and Indonesia. In these countries, private research intensity is lower than in the middle-income countries, but their private research expenditure grew more rapidly than that of the middle-income countries and more rapidly than agricultural GDP, raising research intensity.

Effect of Private Research and Technology Transfer

Companies invest in research to expand markets for their products and to enhance company profits. In addition, private research can contribute significantly to raising agricultural productivity and output. This, in turn, can increase farm income and lower the cost of food for consumers. Below, we identify some areas where private research has had significant economic effects on agriculture in Asia, and briefly review the evidence on the distribution of spillover benefits to farmers and consumers.

Table A-6—Patenting by industries that develop technology for agriculture and other Industries, Asia, 1987-95

Country/year	Unit	Agriculture	Chemicals	Pharmaceuticals	Other machinery	Food	All industries
India, 1992	Number	0	507	81	510	22	1,908
	Percent	0	33	41	29	30	31
China, 1995	Number	6	2,386	1,177	4,460	395	20,585
	Percent	63	37	53	59	65	56
Philippines 1990	Number	0	486	265	114	25	1,091
	Percent	0	8	8	22	13	11
Malaysia 1987	Number	0	314	92	153	15	942
	Percent	0	0	0	3	0	2
South Korea 1995	Number	3	2,519	446	2,640	132	15,210
	Percent	67	36	37	51	77	54

Source: Calculated from Johnson-Evenson Patent Set at *http:\\www.wellesley.edu\Economics\johnson.htm*

Production and Productivity

The major effects of private research on field crop production in Asia have been to increase yields of corn, sunflower, pearl millet, sorghum, and cotton in India; corn and horticultural crop yields in Thailand; corn in the Philippines; and corn and tobacco in Pakistan. Corn yields grew more rapidly than other major crops in Thailand and the Philippines. In India, regression analysis of yields in the semi-arid regions of the country shows that private hybrids of corn, pearl millet, sorghum, and cotton increased yields (Ramaswami and Pray, 1998). The effects on plantation crops of public and private research have been to increase latex yields of rubber and oil palm in Malaysia. In the Philippines, private research increased sugarcane yields and reduced the cost of producing bananas by tailoring fertilizer applications to the soils, reducing fungicide applications, and developing control techniques for pests that are unique to the Philippines. In China, the only effects of private research we have identified were an increase in cotton yields, reduced pesticide use on less than 100,000 hectares, and increased yields in a few areas where private sorghum, maize, and sunflower were planted.

Private animal research and technology transfer has had a significant effect on increasing output and reducing the real prices of animal commodities. The production of poultry, pork, and eggs tripled or quadrupled from the early 1970s to the early 1990s in the countries in this study. Milk production also increased significantly. Much of the growth in animal production was due to increases in inputs. But modern technology allowed the increase in inputs to be used efficiently and increased productivity of animal production. These changes in technology— improved breeds of poultry, swine and cattle; improved feed; veterinary medicine, and confinement management technology—were the result of imported technology combined with the local adaptive research discussed earlier in this paper. In the United States, these improvements cut the real cost (in 1994 dollars) of producing a kilogram of poultry from over $5 in 1955 to about $2.60 in 1965 and then down to about $1.60 in 1994 (Henry and Rothwell, 1995). The private sector played a major role in transferring and adapting this technology to Asia. In Thailand, the feed conversion ratio of broilers improved by 10 to 20 percent, the time to produce a finished bird declined by 10 to 15 days, and the size of the finished bird went from 1 to 1.5 kilogram for each bird. The only study that attempted to measure the effect of technology outside the United States is a recent study by Narrod, Pray, and Peterson (1999). They found that, after controlling for the changes in the ratio of poultry prices to feed prices, modern breeds of poultry and compound feeds were major contributors to the growth in production. These productivity changes are reflected in the declining price of broilers, which has gone steadily downward since the early 1960s (Henry and Rothwell, 1995).

The few studies that measure the effect of private agricultural R&D in developing countries concentrated on crop research, and only a few were conducted in the countries under study here. These studies indicate that private research can increase agricultural productivity and generate positive spillover benefits to farmers and consumers. Ribeiro (1989) estimated the social rate of return to private plant-breeding research in India to be 38 percent or more, depending on the crop. Evenson, Pray, and Rosegrant (1999) measured the effect of private research on total factor productivity (TFP) in India. They found that private sector research, advances in agricultural research outside India, and public research all made major positive contributions to TFP growth in the Indian crop sector. Echeverria (1991) found that private research in tropical countries, including the countries in our study other than China and Malaysia, had an important positive effect on corn yields. He also found that in temperate developing countries, direct imports of corn technology had an important positive influence on yields, but private research did not have a statistically significant effect on yields.

Income Distribution

Studies have shown that a large share of the economic benefits from improvements in food crop production have gone to small-scale farmers and low-income consumers. The effect on income distribution of high-yield varieties of rice and wheat, which was developed by the International Centers and national research systems in these countries, was generally positive in developing countries. Low-income consumers and farmers and landless laborers had larger income gains from the technology than large-scale farmers and wealthy consumers. Some regions without irrigation were left behind, but the negative effects were mitigated to a degree by the movement of laborers to the regions with irrigation (David and Otsuka, 1994).

The income distribution effect of private research on crop hybrids has taken two paths. In some regions of

Thailand, the Philippines, and India, large commercial farmers rapidly turned to production of private hybrid corn and used much of it for animal feed. Thus, the benefits from increased productivity went to larger commercial farmers and to producers and consumers of animal products. Small-scale farmers benefited from producing hybrid corn in many areas of India and the Philippines. Small-scale farmers have also benefited from private hybrid sorghum, hybrid pearl millet (Pray et al., 1991), and hybrid sunflower in India. In areas where small-scale farmers adopted hybrids, the income distribution effect was similar to that of modern high-yield varieties of rice and wheat. Sorghum and pearl millet are primarily eaten as food staples by the poor in the semi-arid regions of India. Thus, poor consumers are important beneficiaries of improved productivity.

The income distribution effect of productivity growth in poultry and pork production has been different from the effect of the major grain crops. The adoption of modern poultry and swine technology has been a phenomenon serving urban markets. In most developing countries, a few large, private integrators have organized poultry production. These large integrators process and market the meat, own the hatcheries that provide baby chicks, own feedmills that provide commercial feed, and organize contract farmers who actually produce the broilers and swine. These integrators undoubtedly capture a considerable amount of the gains from the commercial poultry and pork production, with some benefits reaching the contract farmers who tend to be large-scale farmers. Egg production is less integrated than broiler production. Adoption of commercial technology for eggs was slower than for broilers, but egg production is now largely commercial and concentrated in and around urban areas.

There has been sufficient competition in most countries to dramatically reduce the price of poultry meat and eggs (see Gisselquist and Pray, 1999, for the example of Turkey). The main beneficiaries of the price reductions are mid- and high-income consumers who can afford to eat meat.

Environmental Effect

Private hybrids have the same benefits and costs to the environment as hybrids and improved varieties developed by the public sector. The main environmental advantage is that high yields reduce the pressure to turn more forests, hillsides, and savannas into cropland. The disadvantage is that high-yielding varieties tend to induce farmers to use more fertilizers, pesticides, and irrigation, which may have negative environmental effects. One exception is that plantation research in the Philippines has reduced use of fungicides and chemical fertilizers in banana plantations.

In animal production, modern confinement poultry and swine operations are now major contributors to air and water pollution in many developing countries. These systems create waste that can be useful as fertilizer, but confinement operations that are concentrated around major cities add large amounts of nitrogen and phosphorus to water supplies (Narrod and Pray, 1995). These nutrients cause algal blooms, which lower light penetration and the amount of oxygen in the water, reducing fish production. Economists studying Laguna Bay, a lake near Manila in the Philippines, showed statistically that poultry manure production around the lake reduced fish production in the lake (Pingali, Hossain, and Gerpacio, 1997).

Conceptual Framework for the Country Studies

Economic Determinants of Private Research

Most private agricultural research is directed at developing and supplying improved inputs to farmers. These inputs can be in the form of higher yielding crop varieties or animal breeds, more effective agricultural chemicals or farm machinery, or entirely new kinds of inputs that are more efficient than existing inputs. Private research can also improve the manufacturing of these inputs so that they can be provided at less cost to farmers. All of these types of technical improvements raise farm productivity by lowering the average cost of producing farm products.

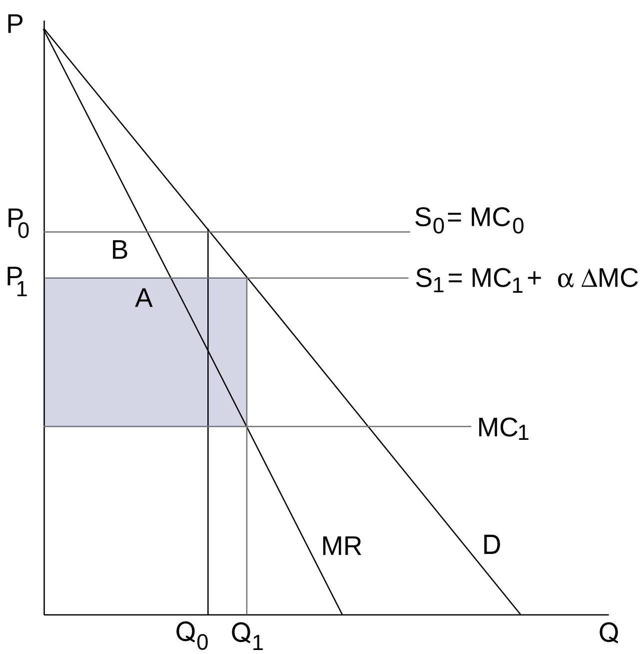
To understand how economic and policy factors affect the incentives for private agricultural research, we need to consider the demand and supply characteristics of farm input markets. Neoclassical theory shows that the demand for a production input is positively related to the price of the final product and negatively related to the input's own price. It is positively related to the prices of other inputs that are substitutes in production, and negatively related to the price of other inputs that are complements in production. The supply function for agricultural inputs can in many cases be considered to be perfectly elastic. For the chemical and machinery industries, for example, the quantity of products supplied to the agricultural sector is usually a small share of the total market for these industries, so shifts in demand from the agricultural sector have little or no effect on the prices of these products. Other inputs, such as animal feed and crop seed, are produced by the farm sector. The supply of these inputs may be less than perfectly elastic.[2]

Figure A-1 presents a conceptual model of the economics of private research for a farm input supplier in which the aggregate farm demand for the input is downward sloping and the industrial supply of the input is competitive and perfectly elastic. In the figure, the initial supply of an agricultural input is given by S_0, which is the marginal cost of producing input Q and is constant for all Q. The market equilibrium price and quantity demanded by farmers for input Q is given by P_0 and Q_0, the intersection of S_0 and D.

For simplicity, assume that private research aims to reduce the cost of producing input Q. This would also apply to research that reduces the costs of manufacturing the input and research that develops a new kind of input to substitute at less cost for an existing input, such as labor-saving machinery or a chemical fertilizer that substitutes for organic fertilizer. Assume that a firm faces a research production function in which a vector of research inputs X is expected to result in a reduction in the marginal cost of producing Q from MC_0 to MC_1, given by $\Delta MC(X)$. We assume that the parameters of the research production function $\Delta MC(X)$ are determined by the present state of scientific knowledge, and that $\Delta MC(X)$ increases with X at a declining rate. In other words, $DMC_x > 0$ and $\Delta MC_{xx} < 0$, where ΔMC_x and ΔMC_{xx} are the first and second derivatives of $\Delta MC(X)$, respectively. Research inputs X are priced at W, so that the private investment in research is X•W. Once made, investment in research is a sunk cost.

[2]See Dasgupta and Stiglitz (1980) for a model examining the relationship between noncompetitive market structure and industrial R&D. Levin and Reiss (1984) present an empirical test of the model.

Figure A-1
Economic benefits from private agricultural research



This research production process mirrors that conceptualized by Evenson and Kislev (1975). They described applied research as a random draw from a distribution of potential experiments, some of which may result in a technology that is better than the current technology. Increasing the number of draws (i.e., increasing the investment in research) increases the probability that a superior technology is drawn. It also increases the expected reduction in marginal cost, compared with the current technology. However, the probability distribution function for the random draws is fixed, and increasing the number of draws produces higher expected gains at a declining rate. Basic research changes the parameters of the probability distribution function for applied research, and thereby increases the expected gains from a given level of applied research. We assume that only the private sector makes investments in applied research and that only the public sector makes investments in basic research.

The new technology developed through private research is provided to farmers in the form of a production input that embodies the new technology developed through research. In a competitive market for farm inputs, the input would be offered to farmers at its marginal cost of production MC_1. Assuming also that the demand for farm output is perfectly elastic (so that the adoption of improved technology does not alter farm output prices), then the full gains of technical change would be passed on to farmers. Since research is a sunk cost, it is not included in the marginal cost of manufacturing the input; therefore, the input manufacturer is unable to recoup the costs of research. In order to capture some benefits of the research, the input supplier must charge farmers a price for the input that is higher than its marginal cost of manufacture. In figure A-1, a firm is assumed a charge a premium for the improved input so that the offer curve for the input is given by S_1 and farmers pay P_1 for the input. The difference between S_1 and MC_1 is the premium charged by the developer of the improved input. This is the profit the input manufacturer earns as a return on its previous investment in research.

The size of the premium is a function of the appropriability of the new technology and other factors. Appropriability is influenced by market structure and how well the new technology can be protected through patents, trade secrets, or other forms of intellectual property protection. If an input manufacturing industry is characterized by one or a few large firms, then a firm may exert market power and set the input price above its marginal cost. A firm may also exercise market power through a patent that gives it an exclusive right to use the new technology. Another possibility is that a firm may keep the technology out of its competitors' hands by keeping key elements of the new technology secret. The production of agricultural chemicals, for example, can sometimes be protected by keeping the manufacturing and formulation process secret even if a patent on the chemical compound itself is not available or has expired. Intellectual property in hybrid varieties can also be protected by restricting access to the parent inbred lines. In this way, a firm can be the sole provider of a technology, at least for a while.

If a firm acted as a pure monopolist, it would maximize profits by supplying the quantity of the input when marginal cost equaled marginal revenue, taking into account the effects of the quantity of input supplied on market price. A monopolist's marginal revenue curve for input Q is shown by MR in figure A-1. The quantity and price that maximize profit are therefore Q_1 and P_1. Monopoly profits are shown by region A, which is the return to private research. Nevertheless, the new input is still offered at a lower price than the old technology, so farmers also realize benefits from the new technology (region B in the figure).

In figure A-1, the monopoly price for the new input P_1 is shown to be less than the price of the old technology P_0. In other situations, P_1 may exceed P_0. However, so long as the old technology remains available in the market at its marginal cost, it provides an upper bound to what a firm could charge with monopoly control over a new technology. A firm could at most charge a farmer P_0, the price of the available technology, otherwise farmers would have no incentive to adopt the new technology. In fact, the firm would likely charge significantly less than P_0 in order to achieve rapid and widespread adoption. Griliches (1957) showed that there is a direct relationship between the size of the economic benefit provided by a new agricultural technology and its speed of diffusion. If a firm charged a price for the new technology that was only a fraction less than P_0, diffusion could be expected to be very slow. Thus, the premium charged by a firm for a new technology is determined not only by the level of appropriability (or market power) in an input market, but also by dynamic considerations of technology diffusion. The firm will balance the price premium earned per unit of input sold with the total quantity of input it can sell. One strategy may be to offer a lower price for the new technology until it is well established, and then raise the price in order to recover the costs of research and market development.

In figure A-1, we abstract away from the dynamics of diffusion and simply assume that a is the share of the reduction in marginal costs a firm charges for a new technology. Then $S_1 = MC_1 + \alpha^* \Delta MC$. Thus, for an input manufacturer considering an investment in research, the expected profit from the research investment X is given by:

$$\pi = P\, Q_1\, \alpha\, \Delta MC(X) - W\, X. \qquad (1)$$

The profit-maximizing level of research is given by the first-order necessary condition that equates $\partial\pi/\partial X = 0$, or

$$P\, Q_1\, \alpha\, \Delta MC_x = W. \qquad (2)$$

The left side of equation 2 is the marginal private benefit of research to a firm. It is a function of appropriability a, market size ($P\, Q_1$), and the technology opportunities described by the research production function $\Delta MC(X)$. The right side of equation 2 is the marginal cost of research given by the prices of research inputs W. Equating private marginal benefits with marginal costs describes the profit-maximizing level of research X for a firm.

Equation 2 can be used to explore how changes in appropriability, market size, technology opportunity, and cost of research inputs influence the optimal level of private research (see table A-7). This is done by taking the total differential of equation 2 with respect to the parameter of interest, and letting X adjust so that the first order of the necessary condition for profit-maximization is maintained.

Consider market size. Taking the total differential of equation 2 with respect to Q_1 (differentiating with respect to P gives a similar result) and solving for $\partial Q_1/\partial X$ gives:

$$\partial X/\partial Q_1 = - \Delta MC_x / (P\, Q_1\, \Delta MC_{xx}) > 0. \qquad (3)$$

Since the marginal returns to research are positive ($\Delta MC_x > 0$) but declining ($\Delta MC_{xx} < 0$), $\partial X/\partial Q_1$ is greater than zero. Thus, an increase in market size increases the optimal level of private research. Similarly, an increase in appropriability a increases the optimal level of private research:

$$\partial X/\partial \alpha = - \Delta MC_x / (\alpha\, \Delta MC_{xx}) > 0. \qquad (4)$$

A decline in the cost of research inputs W would also lead to an increase in the optimal rate of private research:

$$\partial X/\partial W = 1 / (\alpha\, P\, Q_1\, \Delta MC_{xx}) < 0. \qquad (5)$$

Finally, if we define an improvement in technological opportunity to mean that each level of X produces a larger expected reduction in marginal cost, i.e., ΔMC_x is larger for each level of X, then an increase in technological opportunity would also increase the optimal level of private research. Holding other parameters constant, it would require a larger amount of X to equate the expected marginal benefit of private research to its marginal cost according to equation 2. Recall that technological opportunities in the model expand through investments in basic research, which is assumed to be exclusively a public activity.

In addition to providing comparative static results, the model outlined above provides insights into the distribution of benefits from private agricultural research. In figure A-1, the shaded region A is the share of benefits captured by the input developer. Region B is the share of benefits that goes to farmers. So long as the old technology remains available to farmers at its competitive price P_0, private research will never reduce the economic welfare of farmers.

The model could be expanded to consider possible effects of new technology on agricultural commodity price. If final demand is less than perfectly elastic, then private agricultural research could increase total agricultural production sufficiently to reduce output prices. In figure A-1, this would have the effect of shifting the derived input demand function D downward, reducing farm demand for inputs. Lower commodity prices would serve to shift some of the benefits of private research from farmers and the input firm to consumers. In some special circumstances, it is possible for farmers as a group to be left worse off by new technology. But this possibility is not a feature of private research *per se*, but rather is characteristic of any agricultural research, public or private, that occurs under specific market conditions (see Alston, Norton, and Pardey, 1995).[3]

Another modification to the model would be to examine other types of technology improvements provided by private research in addition to those that lower the cost of inputs to farmers. For example, a technology

[3]The downward shift in the input supply function shown in figure A-1 would result in a downward shift in the supply function for the final output, since the marginal cost of commodity production is reduced by lower input costs. A circumstance in which agricultural producers can be left worse off by technical change is when new technology results in a pivotal downward shift of the commodity supply function and when demand for the commodity is inelastic (Alston, Norton, and Pardey, 1995).

Table A-7—Factors affecting private incentives for agricultural research

Parameter	Effect of the parameter in private research
Size of input market	Larger market size increases private research
Appropriability	Greater appropriability increases private research
Technological opportunity	Expanded technological opportunity increases private research
Cost of research inputs	Lower cost of research inputs increases private research

that increases crop or animal yield would have the effect of creating a new derived demand curve that would lie above the old input demand curve D in figure A-1. A firm would recoup costs of research by charging a premium for the new technology above the price of the current technology. The input price premium would need to be less than the economic benefits of higher output yield in order to induce farmers to switch to the new technology.

A further modification could be to consider the effects of risk and uncertainty in research and in future market demand and prices on private research. These modifications to the basic model, while adding to its complexity, are not likely to alter the comparative static results shown in table A-7.

Public Policies and Incentives for Private Agricultural Research

The conceptual model described earlier provides a framework for assessing the likely effect of public policies on incentives for private agricultural research. The model showed that investments in agricultural research by profit-maximizing firms is a function of four main determinants: market size, appropriability, technology opportunity, and the cost of research inputs. Factors 3 and 4 are often grouped together because both are primarily functions of public investments in research and higher education. Public investment in research in basic agricultural sciences and precommercial technology expands the opportunities available for applied research and development by the private sector. Public investment in agricultural postsecondary and graduate education increases the availability of agricultural scientists and technicians. This reduces the cost of conducting research, since human capital is often the largest single component of research costs.

Table A-8 describes how different policies may affect these determinants. First, there is the general economic environment. Macroeconomic stability, good transportation and communication infrastructure, functioning capital and insurance markets, and a reasonable level of general education and training, especially agricultural training, are factors that positively affect all the determinants. These factors reduce the costs of transacting business in an economy, including agricultural research and the delivery of improved inputs to farmers (Evenson and Westphal, 1995).

In addition to these general conditions, the size of input markets is affected by several specific policies. In some countries, state-owned enterprises maintain a monopoly on the production and/or distribution of cer-

Table A-8—Policies and incentives for private agricultural research, Asia, 1998

Private research determinants	Policies affecting determinants
General state of the economy	Macroeconomic stability Public infrastructure General education and training Development of capital and insurance markets
Size of input markets	Market share of state-owned enterprises Restrictions of foreign participation in input markets Trade restrictions on inputs Price interventions in input or product markets
Appropriability	Intellectual property laws (patents, plant breeders' rights, trademarks, trade secret protection) and enforcement
	Technology-licensing requirements and regulations affecting technology imports
	Competitiveness and antitrust policies
Technological opportunity and cost of research inputs	Public investment in agricultural research and education Trade restrictions on inputs and restrictions on foreign direct invest ment
	Registration and testing requirements on new seed and agricultural chemicals
	Biosafety requirements for biotechnology field trials
	Public subsidies for private research, including tax holidays, tax credits, research grants, and technology parks

tain agricultural inputs. Limiting the access of the private sector to input markets acts as a disincentive to private research. Similarly, some countries may pursue protectionist policies to help national industries and limit the degree to which foreign companies can participate in local markets. These restrictions may be outright bans of foreign input firms, regulations that require majority control by a local partner in a foreign subsidiary, restrictions on the foreign remuneration of profits, or regulations on foreign direct investment. These restrictions can reduce the incentives for private research in a country by multinational firms. Moreover, empirical research shows that protectionist policies retard the technological development of national industries by blocking access to critical elements of foreign technology (Evenson and Westphal, 1995).

Government intervention in agricultural input or output markets may also take other forms. Subsidies that increase farm prices increase farm demand for inputs, and likewise explicit or implicit taxes on agriculture reduce farm demand for inputs. Prices of inputs themselves may be subsidized or taxed, similarly affecting input demand and, therefore, the size of the market for improved inputs.

Appropriability is affected by policies toward intellectual property rights (IPRs), trade secret protection, and market competitiveness (e.g., antitrust policy). Several countries have until recently excluded agricultural inventions from patent protection. And even in countries with legal protection for patents and trademarks, enforcement may be lax or cumbersome. However, under the Uruguay Round of the GATT (General Agreement on Tariffs and Trade, which is now the World Trade Organization), member countries are required to provide IPRs for agricultural and other inventions, including new plant varieties. Otherwise they may face retaliatory trade measures.

National laws influence a firm's ability to protect technology through trade secrets. Some countries require foreign companies to import and license their technology locally in order to participate in local markets. For example, agricultural chemical companies may be required to manufacture active ingredients locally, or seed companies may be required to import advanced breeding material and produce hybrid seed locally for sale. While technology importation and licensing requirements are often designed to increase technology transfer, they can also cause companies to stay out of a market completely. Since maintaining control over proprietary technology is critical for appropriating gains from research, multinational companies may be reluctant to participate in markets that put their patented technology and trade secrets at risk.

A recent survey of U.S. manufacturing companies suggests that the strength of IPRs and a government's willingness to enforce them influence firms' willingness to license technology, transfer it through their subsidiaries, and conduct research in a country (Mansfield, 1994). In the survey, Mansfield asked companies whether strong IPRs or the lack of them influenced the companies' willingness to transfer technology to a country. Companies were also asked to rate the strength of IPR protections in 16 countries. Eighty percent of the companies said that IPRs had a strong effect on their decision to invest in research and development (R&D) facilities. Only 20 percent of them, however, said that the strength or weakness of IPRs had a strong effect on their decision to establish sales and distribution outlets. Of the 16 countries named in the survey, Brazil, India, Nigeria, and Thailand were seen as having weak laws, while Hong Kong, Japan, Singapore, and Spain were perceived as having relatively strong laws. In Asia, only 8 percent of the companies surveyed indicated that they thought Japanese IPRs were too weak to permit licensing of their newest and most effective technology. But 38 percent thought Thailand's IPRs were too weak, and 44 percent thought Indian IPR laws would not protect their newest and best technologies.

Antitrust or competitiveness laws also affect the appropriability of private research. Schumpeter (1950) hypothesized that industries with a concentrated market structure have higher rates of technical change, because it is generally easier for a company to appropriate the gains from research when it has sufficient market power to influence prices. Such market power is usually enhanced when a company gains a large share of a market with significant barriers to entry of potential rival firms. However, too little competition can reduce incentives for private research. A firm facing little or no competition may see little need to devote resources to research and innovation, and be content to charge monopoly prices for old technology. Scherer (1980, page 438) summarizes the findings of subsequent research on Schumpeter's early theory:

> *A bit of monopoly power in the form of structural concentration is conducive to invention and innovation, particularly when the advances in the relevant*

knowledge base occur slowly. But very high concentration has a favorable effect only in rare cases, and more often it is apt to retard progress by restricting the number of independent sources of initiative and by dampening firms' incentive to gain market position through accelerated research and development (page 438).

The main policies affecting technology opportunity and the cost of research inputs are public investments in agricultural research and higher education. A strong public agricultural research and university system can significantly reduce the cost of private research by expanding the supply of highly skilled scientific and technical personnel available for private agricultural research. Public research can also provide key enabling technologies that increase the likelihood that private research endeavors will be successful. For example, in the 1960s, public research helped identify sources of varietal resistance to downy mildew, a major corn disease in southeast Asia. This provided an impetus to private seed companies to expand their research in corn breeding in the region. In the United States, public research developed many basic scientific tools for genetic engineering and helped launch the biotechnology industry.

Restrictions on imports of technology and foreign direct investment can also reduce technological opportunity. If these restrictions keep out new foreign technology and research by foreign firms, there will be less spillover of technology and knowledge to local firms. If farmers are using the foreign technology, local firms can improve and adapt it to local conditions. If foreign firms conduct research in the country, the scientists they hire can eventually leave and start their own firms to compete against the foreign firm.

Regulatory policy also influences technology opportunities and the cost of conducting research in a country. Countries differ in their requirements for efficacy and safety testing for registering new pesticides, which affects the time and cost of introducing new products into a market. Countries also differ in their regulations governing the introduction of new seed varieties. Some countries allow only varieties that have been demonstrated to be superior to existing varieties to be released and sold to farmers. Other countries allow companies to market any new variety they develop, relying on market competition to provide an incentive to seed companies not to introduce low-quality varieties. With respect to biotechnology, some countries have moved quickly to establish protocols for conducting field trials with genetically modified plants in order to encourage applications to agriculture. Other countries have not yet developed protocols or used very strict ones to discourage biotechnology.

Finally, governments may provide direct subsidies to private research in the form of research grants, research tax credits or tax holidays, or more indirect subsidies such as public investments in technology parks. Through technology parks, governments may provide research infrastructure to private firms at a subsidy. Technology parks may help create a critical mass of private entrepreneurs in order to establish a new industry or to commercialize the results of research from public research institutes and universities.

Global Forces Affecting Private Agricultural Research in Asia

Growth in Consumer Demand for Food

The model discussed earlier indicates that large markets induce more private research. Thus, the largest agricultural sectors should attract the most private agricultural research, and those growing most rapidly should have the most rapid growth of private research. Figure A-1 shows a weak positive relationship between private research expenditures and agricultural gross domestic product (GDP). Table A-2 also shows a weak relationship between private research intensity and agricultural GDP. Note that if research and agricultural GDP were perfectly correlated, then all countries would have the same research intensity. Instead, China and Indonesia have very low research intensities relative to other countries in our sample, while Malaysia and Indonesia have high research intensities.

A major factor that led to the increase in private agricultural R&D in Asia was increased demand for agricultural production at a time when investments in traditional sources of growth—land expansion, irrigation, additional agricultural labor, and public research—were slowing down or declining. In addition, demand for higher value agricultural commodities—meat, fruits, and vegetables—was growing particularly fast. Demand for more agricultural goods leads to demand for more modern inputs. As sales of modern inputs grow, private input firms and plantations revise upward their expectations about the future returns to research.

Also, these firms have more money to spend on research from input sales. These factors lead to higher expenditures on research by these firms.

There seems to be a closer relationship between growth of private agricultural research and growth in agricultural GDP. Research intensity remained roughly constant from the mid-1980s to the mid-1990s in Thailand, Malaysia, and the Philippines (table A-2). Thus, research and production were growing at roughly the same rate, which suggests that the growth in value of agricultural production accounts for most of the growth in private research in these countries. However, in India, Pakistan, and Indonesia, private research intensity nearly doubled. Thus, only part of the growth in research intensity can be accounted for by agricultural GDP growth. In China, the starting point for private research was zero, so growth was even more rapid. In these countries, we have other explanations for the sources of growth in private agricultural research.

Growth in the International Supply of Agricultural Technology

The period since 1985 has seen agricultural biotechnology functioning in the United States and elsewhere. There has also been a tremendous growth in large multinational firms in the agricultural input industries and the food trade and processing industries. These two trends are closely related. One of the most significant areas of consolidation in market structure has been the development of life-science biotechnology firms out of what had been chemical and pharmaceutical firms. These trends fit into our model of private research by providing new technological opportunities and increasing the efficiency of research by Asian firms and Asian affiliates of the multinationals.

Two types of evidence show the importance of these trends for Asia. First, about half of the research conducted in the seven countries included in this study is being done by foreign firms (table A-5). They perform the majority of the private research in all countries except India, Pakistan, and Malaysia. Second, foreign firms are concentrated in the industries where private agricultural R&D has been growing most rapidly—chemicals, livestock, and seed—and play a small role in private plantation and machinery research, where R&D growth has been slower.

Most foreign firms conducting agricultural research in Asia have their headquarters in industrialized countries where they conduct a substantial proportion of their firm's research. Private agricultural research in industrialized countries accounts for half of total agricultural research in these countries and is growing about 5 percent annually, more rapidly than public agricultural research (Alston, Pardey, and Roseboom, 1998). This growth was driven by breakthroughs in biotechnology and information technology, stronger intellectual property rights, and expectations of relatively high prices for agricultural commodities (Fuglie et al., 1996). Firms have made these investments in agricultural research to develop new crop varieties, veterinary pharmaceuticals, agricultural chemicals, and machinery. They are now looking for ways to market these new products worldwide to pay for their research. Asia is one of the targets for these marketing efforts.

Changes in the demand for agricultural inputs in the United States, Europe, and Asia have made the markets of countries of Asia look very attractive relative to U.S. firms' traditional markets. Three major U.S. agricultural input firms—Monsanto, DuPont, and John Deere—reported to us that since 1985 they have made major policy decisions to expand into Asia and other developing countries. From World War II to the late 1970s were boom years for agricultural input firms in the United States, Europe, and to a lesser extent Latin America. The 1980s were a period of stagnant or declining growth. Starting in the mid-1980s, many U.S. companies reacted to stagnant market size by reducing costs. By the early 1990s, opportunities for further cost reductions were limited. At this point, many of them started to look to new potential markets in developing countries, Central Europe, and countries of the former Soviet Union for further growth. Asia, in particular, looked attractive because of the rapid growth in demand for modern inputs, especially for labor-saving inputs such as herbicides and tractors. John Deere, DuPont, and Monsanto specialize in these kinds of inputs, so their decision to expand into Asia in the 1990s is not surprising.

Mergers and acquisitions by the United States and European life-science companies appear to be increasing the flow of new technology to Asia. Mergers and acquisitions in the agricultural input industries and food industries in the United States and Europe have been fueled by developments in these countries such as biotechnology, the expansion of the stock market, and a drive to achieve economies of scale and scope. Much of the consolidation centers on the chemical and pharmaceutical multinational corporations (MNCs). Firms sold their chemical manufacturing and marketing components in order to raise money for increased investments in high-technology and high-profit products in pharmaceuticals, veterinary medicine, pesticides, and biotechnology. One of the earliest of these decisions was by ICI (the British chemical firm), which split into ICI for the traditional bulk chemicals and Zeneca to concentrate on drugs, pesticides, seeds, and agricultural biotechnology. In 1997, the U.S. firm, Monsanto, announced it would sell its bulk chemicals business to concentrate on the high-technology life sciences. Later, DuPont sold its gasoline business and invested heavily in a joint venture with Pioneer Hi-Bred, a large U.S. seed company.

A second trend is the merger of large chemical and pharmaceutical firms (see the first column in table A-9). The German firms Hoechst and Schering formed a joint venture for their agricultural and environmental products called AgrEvo. The Swiss firms Ciba-Geigy and Sandoz merged in 1997 to become Novartis. Merck of the United States and Rhone-Poulenc of France formed a new joint venture for their animal products (veterinary medicines and poultry genetics) called Merial Animal Health. As recently as 1999, Hoechst and Rhone-Poulenc merged to form Aventis.

These large chemical firms used the money raised from selling their chemical businesses to fund research and development and to buy small biotechnology firms and seed companies or, in some cases to negotiate strategic alliances with them. Table A-9 shows some key purchases of biotechnology and seed firms. AgrEvo purchased Plant Genetic Systems, the largest European plant biotechnology firm, in 1996. More recently, it purchased Cargill's U.S. seed business. DuPont purchased 20 percent of Pioneer Hi-Bred. Monsanto has been the most active of all. It bought into three important biotechnology firms, purchasing 100 percent of Agracetus and Calgene and all of the technology assets of Ecogen. Monsanto also purchased the corn and soybean seed businesses of Asgrow (the second largest soybean seed producer), Holdens Foundation Seeds (the largest foundation seed firm in the United States), DeKalb (the second largest hybrid corn firm), and Cargill's international seed business. Monsanto tried to acquire Delta and Pineland, the largest cottonseed producer in the United States, but subsequently dropped that pursuit.

These purchases brought these large life-science companies into the seed business of many developing countries in 1998. In addition, they purchased firms or entered into joint ventures with local seed companies in these countries. This gave them a market for the plant biotechnology products that they have developed through their own research and the research of the firms they purchased. Table A-10 documents the purchase and joint ventures of the major U.S. and European life-science companies with local seed firms in India, China, Southeast Asia, and Latin America.

A small but growing trend in industry structure is the purchase of technology-based companies in industrialized countries by emerging MNCs from developing countries. A pioneer in this area was the Thai firm Charoen Pokphand, which has extensive business interests in Southeast Asia, China, and the United States. It has a long history of joint ventures in Asian countries, with DeKalb for seed and Arbor Acres for poultry genetics. However, recently it decided to purchase the U.S. broiler-breeding company Avian Farms to give it another source of poultry genetics. More recently, the Mexican firm Empresas La Moderna purchased the U.S. biotechnology company DNA Plant Technology and vegetable seed companies Seminis, Peto Seeds, and Asgrow Seeds. It then sold Asgrow's corn and soybean business to Monsanto and kept the vegetable part of Asgrow.

The emergence of biotechnology and changes in the structure of the international agricultural input industries helped to stimulate more private agricultural research in Asia. Monsanto's investments in biotechnology, chemical, and seed research have been important sources of new opportunities and funds for research in India, China, and Thailand. AgrEvo is investing in biotechnology research and seed industries in India and China. DuPont is expanding its research in China and India.

Although the breakthroughs in biotechnology may be pushing the structural changes in the international agricultural input industries, so far biotechnology has had limited direct effect on food production or private R&D in Asia. The technological opportunities created by the new tools of biotechnology first stimulated private research in the early 1980s in Malaysia. Plantation companies thought that tissue culture would allow them to develop high-yielding oil palm clones. Despite considerable amounts of money and time, this research has yet to prove profitable. The second wave of biotechnology research has been in the seed industry. Major seed firms are testing transgenic corn, cotton, rapeseed, and soybeans in greenhouses or confined plots. In China, India, and Thailand, seed companies

Table A-9—Mergers and acquisitions in agricultural chemicals, biotechnology, seeds, and food/feed, Asia, 1994-98

Parent company	Agricultural chemicals	Biotech	Seeds	Food/feed
Monsanto		Calgene Agracetus Ecogen (13 percent) Millenium Pharmaceutical (JV for crops genes)	DeKalb, Asgrow corn and soybeans, Holden's Foundation Seed, Delta & Pineland (not yet approved), Cargill International Seeds, Plant Breeding International Cambridge.	Cargill JV feed and food (Monsanto already has brands like Nutrasweet).
AgrEvo	1994, merger of Hoechst and Schering plant agriculture business.	Plant Genetic Systems PlantTec.	1997, Nunhems Plant Genetic Systems, Pioneer Vegetable Genetics, Sunseeds; 1998, Cargill U.S. Seeds.	
Novartis	1996, merger of Ciba-Geigy and Sandoz; 1997 buys Merck's crop protection business for $910 million.		1996, merger brings together Northrup-King, S&G Seeds, Hilleshog, Ciba Seeds, Rogers Seed Co.	
Dow Chemicals	1997, Dow purchases Eli Lilly's 40% share of Dow Elanco for $900 million; 1997, buys Sentrachem Ltd. of South Africa $495 million.	Mycogen 1996 Ribozyme Pharmaceuticals Inc.	1996, United AgriSeeds becomes part of Mycogen; 1992, Mycogen bought Agrigenetics.	
Zeneca	1997, Ishihara Sangyo Kaisha.	1997, Mogen International N.V.	Advanta (merger of Zeneca seed and Vanderhave).	
DuPont			1997, Pioneer (20%) Hybrinova (France).	Quality Grain (JV with Pioneer), Protein Technologies (food), Cereal Innovation Centre (United Kingdom).
Empresas La Moderna/ Seminis		DNA Plant Technology.	Asgrow vegetables, Petoseed, Royal Sluis, Seminis (ELM owns 62%, George Ball, Jr., the rest).	Bionova.
Rhone-Poulenc	December 1998, discussing merger with Hoechst.	Limagrain (alliance) owns Nickersons, Vilmorin, Ferry Morse, and others.		
Merck	Merial Animal Health a JV with Rhone-Poulenc.			

Table A-10—Effect of mergers and acquisitions on U.S., Indian, Chinese, and Latin American seed industries, 1998

Parent company (main business)	U.S./European seed companies	Indian seed companies	Chinese seed companies	S.E. Asia	Brazil and Argentina
Monsanto (U.S. agricultural chemicals, pharmaceuticals, food additives)	Holden's DeKalb Asgrow (soybeans and corn) Stoneville Delta & Pineland, Cargill International Seed Business	MAHYCO (50-50 cotton Monsanto; 26% of MAHYCO) E.I.D. Parry (corn, sorghum and sunflower with DeKalb), and Cargill	CASIG (corn with DeKalb), Xingjiang, and Shaanxi Provincial Seed Companies Hebei Provincial Seed Co. (cotton Delta & Pineland), Cargill (Liaoning)	DeKalb (JV with Charoen Pakpoen) Cargill	Agroceres (Brazil) Asgrow DeKalb Monsoy (Brazil), and Cargill
DuPont (U.S. chemicals, oil, fiber & food)	Pioneer	Southern Petrochemicals (Pioneer)	Pioneer Research Subsidiary	Pioneer	Pioneer
Aventis (German French agricultural chemical, pharmaceuticals)	AgrEvo PGS Nunhems	Proagro Sunseeds	Sunseeds JV	Sunseeds	Sunseeds JV in Chile Granja 4 Irmaos S.A. (Brazilian rice breeder)
Novartis (Swiss agricultural chemicals and pharmaceuticals, and food)	Northrup King	Novartis (was Sandoz)		Novartis (was Ciba Seeds)	Northrup King
Astra/Zeneca (Swedish/U.K. agriculture chemicals and human health)	Advanta	ITC/Zeneca	Advanta	Advanta (was Pacific Seeds)	None
Dow (U.S. chemicals)	Mycogen	None	None	None	Morgan SA (Argentine), Dinamilho (Brazil)
Empresas La Moderna (Mexican agribusiness)	Seminis Peto Asgrow (vegetables) George Ball	MAHYCO (Asgrow), Nath Slius, Indo-American Seeds	Petoseeds has JV with CASIG and subsdiary in Shanghai	Petoseeds	Petoseeds

are conducting government-approved field trials of transgenic plants. China is the only country of this group that has approved the commercial use of transgenic plants developed by a private firm; Monsanto is selling its transgenic cottonseed in China.

Effect of Country Policies on Private Agricultural Research in Asia

In addition to the global forces described earlier, policies undertaken in individual Asian countries have also influenced incentives for private agricultural research and technology transfer in those countries. Probably the most important policy change has been market liberalization and greater participation by foreign firms in domestic markets.

Market Liberalization and Competition Policy

The major policy changes that stimulated more private research in Asia were eliminating public monopolies, reducing subsidies for public sector input firms, and allowing foreign firms to play a larger role in input industries. The most liberal market economies in the mid-1980s—Thailand, Malaysia, and the Philippines—had the highest private research intensities at that time. The countries with the most controlled economies—China, Indonesia, Pakistan, and India—had the lowest private research intensities.

The countries in which private research intensity grew most rapidly—China, India, Pakistan, and Indonesia—had major liberalization programs during the mid-1980s (table A-11). China allowed foreign firms into the seed, pesticide, feed, and agricultural machinery as joint-venture partners starting in the late 1980s, although there were still restrictions. Before the late 1980s, only a few poultry genetics firms had been allowed to sell technology in China. In India, the government gradually reduced restrictions on the foreign input firms—particularly in the seed industry but also in pesticides and agricultural machinery where foreign firms had been restricted to being minority partners in joint ventures. In the 1980s, Pakistan and Indonesia reduced the role of the public sector in supplying subsidized inputs to farmers. In addition, Pakistan had a strong policy of privatization and liberalization after 1988. None of these countries eliminated or even substantially reduced the size of the government corporations in the agricultural input industries, but they did level the playing field by reducing subsidies and eliminating monopoly powers of state-owned enterprises.

Malaysia, Thailand, and the Philippines already had private input industries before 1985. Furthermore, the plantation sector, where much of the private agricultural research in these countries is concentrated, was held by private firms. The Philippines was the only country that made important changes after 1985, when it reduced subsidies and political favors to one large input firm, Planters Products, which was run by associates of then-President Marcos.

Intellectual Property Rights

Firms do not conduct research unless there is some way to capture some of the benefits from research and turn them into profits—which is called appropriability in our model. In Asia, input firms have primarily used technical means (i.e., product formulations that are difficult to copy) of protecting their intellectual property. Seed companies protect new plant varieties by producing only hybrids. Chemical companies protect new pesticides or pharmaceuticals by keeping the process of production secret and by making chemicals that are difficult to reproduce. Plantation owners capture benefits of research by developing technology for use on their own plantations.

Patents and other forms of intellectual property rights (IPRs) have not played a very significant role in stimulating private research in these countries. In fact, the empirical relationship between the strength of the patent system and private research in these countries is weak—perhaps because none of the countries had strong intellectual property rights systems in the 1980s and 1990s (table A-12). China and Indonesia, with no patent system for agricultural inventions at the beginning of the period, had the lowest research intensity in the mid-1980s, and Malaysia, with the strongest laws, had the highest research intensity. However, Pakistan, which had stronger IPR laws than India (although both had very weak enforcement), had much lower research intensity than India which had IPRs with less coverage.

Nor is the strengthening of IPRs strongly associated with growth in private research. There were some substantial changes in policies during this period (table A-12), but they are not consistently related to changes in research intensity. For example, Malaysia and Thailand made improvements to their patent laws but had declining research intensity. India and Pakistan, which

Table A-11—Industrial policy changes, impact, and future policy options

Countries	Industrial policy changes since mid-1980s	Effect: increase in private R&D	Further policy options
China	Allows foreign firms 20% of pesticide, JVs in seed and poultry hatcheries.	More than $16 million	Reduce subsidies to parastatals, allow foreign and local private larger share of market; and allow foreign firms to be majority shareholders in joint ventures in seed and agricultural chemicals.
India	Allows foreign firms & large Indian firms into seed and biotech industry. Government corn seed sales from 4,842 metric tons in 1981 to 3,984 metric ton in 1991. After 1991, wholly owned subsidiaries of foreign firms allowed in most industries. Barriers to imports of active ingredients of pesticides reduced.	More than $3.6-million seed industry More than $8 million in pesticide R&D	Allow imports of agricultural inputs.
Malaysia	Promoted privatization and foreign investment.	Small effect	Restrictions on foreign investment in tree and crop production.
Thailand	Promoted privatization and foreign investment before 1985. Government corn seed sales from 2,000 metric tons in 1980s to 5 metric tons in 1995.	Small effect	
Indonesia	Pesticide subsidies reduced, and private companies allowed to market pesticides to farmers.	More than $1.6 million in pesticide R&D	Restrictions on private investments in plantations.
Philippines	Role of planter products in distributing subsidized inputs eliminated. Import barriers on inputs reduced.	More than $0.8 million in pesticide R&D	
Pakistan	Early 1980s, pesticide distribution privatized. Since 1988, privatization of processing industries.		Punjab and Sind Seed Corporations still major seed suppliers.

Table A-12—Intellectual property rights, Asia, 1979-98

Countries	IPRs in 1980	IPR changes since mid-1980s	Current exclusions	Further policy options
China	No patent law.	Invention patent system and petty patent system in 1985; coverage extended to agriculture chemicals in 1993; successful lawsuit by American Cyanamid against copying 1997; and plant breeders' rights passed 1997.	Only plants and biotech products excluded.	Administration to enforce plant breeders' rights for stronger enforcement of patents.
India	Patent law excludes product patents on chemicals, plants, and food	No major changes, and revised patent law and plant breeders' rights proposed to parliament but not passed.	Agriculture chemicals, pharmaceuticals, foods, plants, and biotech excluded.	Change legislation to include excluded products and better enforcement.
Malaysia	Patent law only excludes plants.	Stronger patent law passed 1986.		
Thailand	1979 patent law included pesticides, excluded agriculture machines and plants.	1992 patent law extended coverage to farm machinery, biotechnology processes, and genetic sequences. Plant breeders' rights before parliament.	Plant and animal life forms excluded.	
Indonesia	No patent law.	1991 patent law.	Plants, animals, biotech	
Philippines	Patent law only excluded plants; weak patents allowed.	No major changes. Plant breeders' rights proposed to parliament but not passed. New patent regulations were passed in 1997.	Plants, animals, biotech	
Pakistan	Patent law only excluded plants.	No major changes. Plant breeders' rights proposed to parliament but not passed.	Plants, animals, biotech	

had very limited changes in IPRs during this period, had the most rapid growth in research intensity.

Investments in Public Agricultural Research

The relationship between public and private research can be one of either substitutes or complements. If public research institutions develop and disseminate technologies similar to those developed by private companies, then public research could discourage the private sector from investing in new technology. However, public research can provide important "upstream" science and technology for private firms to adapt into applied product innovations. Public research institutions and universities also reduce the cost of research inputs for private companies, especially by expanding the available pool of scientific and technical personnel.

In most instances, we find evidence of strong complementarities between public and private agricultural research in Asia. Public research provided basic technology such as downy mildew-resistant corn in southeast Asia and downy mildew-resistant pearl millet in India. These breakthroughs allowed the development of the hybrid seed industries in south and southeast Asia. A survey of Indian private plant breeders found that the Indian public research system has been a major source of breeding material for cotton and sorghum, while the International Center for Research in the Semi-Arid Tropics (ICRISAT) has been a major source of germplasm for pearl millet (Pray, Kelley, and Ramaswami, 1998). In China, two emerging local private research firms are evolving out of provincial hybrid rice and hybrid corn research programs (see the China case study section).

In addition, public research is providing technology to improve seed firms' appropriability. Hybrid rice is the focus of much private research in India and some private research in the Philippines, Pakistan, and Thailand due to the work of the International Rice Research Institute (IRRI) and national government programs that developed hybrid rice technology for the Tropics. In addition, hybrid mustard, developed by Indian universities and European firms, and techniques like genetic fingerprinting, developed in part by public institutions in industrialized countries, are providing technical means of capturing more of the gains of private research.

Public research has also been very important as a source of scientists for private research. Almost all Asian private-sector plant breeders first worked in government research institutes and/or international agricultural research centers. This is not surprising because there is virtually no place else to hire trained scientists. The important point is that firms are likely to invest more in research in countries with many well-trained agricultural scientists.

Between 1971 and 1991, public research grew much more rapidly in developing countries than in industrialized countries. In low-income Asian countries, research expenditures grew by 8.9 percent in 1971-80 and 6.0 percent in 1981-93. In middle-income countries, research expenditures grew by 6.8 and 6.4 percent in the same periods (Alston, Pardey, and Roseboom, 1998). From 1971 to the early 1990s, public research intensity grew in all countries in our sample except China.

Public and private research expenditures and research intensities are positively related in the Asian countries in our sample. In 1985 and 1995, public and private research intensities were highest in Malaysia and Thailand and lowest in Indonesia (table A-13). There is no obvious connection between growth in private research and high research intensity or high rates of public sector growth (table A-13). China's and Indonesia's public research grew slowly but had the highest private research growth. Thailand had the second highest growth of public research in 1981-93, but private research there grew relatively slowly.

Public sector flows of agricultural technology between industrial and developing countries through international agricultural research increased markedly after 1960 but recently began to ebb. The most notable development was the establishment of the Consultative Group for International Agricultural Research (CGIAR) system of international agricultural research centers (IARCs). This evolved into an effective system for breeding and transferring new crop varieties and germplasm to national agricultural research programs in developing countries. Advanced germplasm provided by IARCs has also benefited industrialized countries.

Funding for the international agricultural research centers declined in real terms since the early 1990s. The decline in real funding at the four original centers—IRRI (for rice, located in the Philippines), ICRISAT (pearl millet and sorghum, located in India), International Maize and Wheat Improvement Center (CIMMYT) (maize and wheat, located in Mexico),

Table A-13—Agricultural research expenditures, Asia, 1985 and 1995

Country	Public 1985	Public 1995	Public Growth	Private 1985	Private 1995	Private Growth
	Millions of 1995 U.S. dollars		*Percent*	*Millions of 1995 U.S. dollars*		*Percent*
India	206	348	69	26	56	116
China	403	485	20	0	16	Infinite
Indonesia	62	81	31	3	6	118
Malaysia	44	64	44	14	17	18
Philippines	17	38	113	6	11	69
Thailand	67	127	89	11	17	64
Pakistan				2	6	138
Total	800	1,142	43	62	128	99

Source: Country case studies.

and International Center for Tropical Agriculture (CIAT) (rice, cassava, and beans, located in Colombia)—started in the late 1980s (Alston, Pardey, and Roseboom, 1998). Of these centers, IRRI, ICRISAT, and CIMMYT have had major effects in Asia, including helping to stimulate more private seed research by providing a better pool of crop germplasm. As of 1998, there was no evidence that the decline in research by international centers had reduced the private sector's technological opportunities. This may be because the small decline in international center research is offset by the large increase in technological opportunity due to the increased interest in Asia by large private multinationals.

Most government research programs in Asia are now implementing or at least considering ways to strengthen linkages between public and private agricultural research. This is taking more concrete form in several countries. One approach is to establish government programs to fund joint public-private research projects. Indonesia, Thailand, and India have developed programs of this type. Another approach is to require public research institutions to raise a certain proportion of their research budgets from the private sector, such as through product sales. Public research can stimulate private research by selling research inputs such as plant germplasm to the private firms. So far, most systems are selling finished technology or other nonscience assets such as land. China is the furthest in the privatization process. About 40 percent of the revenue of China's public research system comes from commercial enterprises, but most of that is from nonscience assets and does little to stimulate private research (Pray, 1999). The aim of privatization of public research in Malaysia is that eventually 60 percent of the money will be from private sources. The Indian Council for Agricultural Research is setting 20 percent as its goal.

Research Subsidies and Tax Incentives

In recent years, Asian governments have started to offer special subsidies and tax benefits to encourage private research. For several years, Malaysia has had an R&D tax credit program that allows firms to write off 200 percent of their research expenditures from their corporate income taxes. In 1997, India introduced a 120-percent R&D tax credit. The Philippines, Malaysia, Thailand, and some Indian states have invested public resources to establish research parks, some of them specifically for biotechnology-related food and agriculture. Research parks are designed to encourage private research by improving access to research facilities and public research institutions

From our interviews with private companies, we found little evidence that the tax policies or the research parks have had an important effect on private research. Most of these policies had just been established. Thailand has had an R&D tax credit for a number of years, but none of the firms we interviewed were aware of the tax credit or took it into account in their research investment decisions. However, in the 1980s, the Thailand Board of Investments introduced incentives for the seed industry, including a 10-year tax holiday for new seed companies, a waiver of import duties on research equipment and materials, and permission for foreign companies to own agricultural land for research purposes. Some firms acknowledged that this was an important incentive for them to invest in seed processing and research in Thailand.

Regulations for Public Health, Environmental Protection, and Product Efficacy

To protect farmers and consumers from health and environmental hazards, fraud and product mislabeling, and potentially harmful plant and animal diseases, governments have developed an extensive set of regulations on new plant varieties, seed and animal imports, pesticides, agricultural machinery, and food. Some new regulations have received additional support from industries that wish to use them as nontariff barriers against foreign competition. Multinational corporations often encourage the development of environmental and safety regulations because they will raise the cost of production of local firms. Regulations in foreign countries that import agricultural products from Asia also influence local regulations.

Some of these regulations can have an important effect on R&D. Establishing a clear and consistent regulatory regime for agricultural inputs can encourage private companies to undertake research. For example, few international companies are willing to do research on transgenic plants unless a country has some system for government regulation of testing because the negative publicity of such activity in the absence of an approved regulatory framework would be too great. Thus, while private research on transgenic plants is being conducted in Thailand, China, and India, none is being conducted in the Philippines because the Philippines has not approved testing of transgenic plants in the field. However, excessive regulation reduces the amount of private research. Mandatory government testing and registration of new crop varieties developed by private companies can add years and tens of thousands of dollars of research costs. This reduces the rate of return to investments in research and thus acts as a disincentive for private breeders.

Table A-14 lists the regulations that are in place on seeds, pesticides, and biotechnology for several Asian countries in 1997-98. In general, China and Thailand have placed the least emphasis on environmental and safety regulations and the most emphasis on obtaining technology quickly in all industries. India, Malaysia, and the Philippines have been at the other end of the spectrum, with more emphasis on environmental and safety regulations. This often leads to a longer lag between the time when research is conducted and the time the new technology reaches farmers. International chemical firms reported that in the past regulations did lead companies to test and market chemicals more rapidly in Thailand than in India. However, recent changes in the way the Indian regulatory system works seem to have increased their interest in doing research in India. As mentioned earlier, the lack of regulations for testing genetically engineered plants in the field has meant that private agricultural biotechnology research is being conducted in Thailand, China, and India but not in the Philippines.

The seed industry is the one industry that is an exception to the statement that China has the least regulation and India the most. India (along with Thailand and the Philippines) has voluntary testing and registration of varieties, while China has mandatory testing and registration. This has been one of the reasons Thailand and India have most of the private plant breeding research in Asia. Mandatory testing and registration of new varieties has also discouraged private seed research in Indonesia.

Policy Options for Developing Countries

The country case studies provide several lessons for policies and policy options for developing countries that wish to encourage the private sector to invest in agricultural research and technology transfer in their countries. Some of the major lessons are described in this section.

Sequencing of Policies

The country case studies provide clear evidence that certain policies will have little effect on private research unless a country meets certain prior conditions, has passed through some minimum stages of development, and has some key policies in place. For example, passing plant breeders' rights legislation or strengthening the patent system when there is no demand for modern seed or when the seed industry is a government monopoly will not stimulate private research. Likewise, tax incentives and research parks will not stimulate small biotechnology firms if intellectual property rights are weak or there is no possibility of field-testing and commercializing genetically modified organisms.

The first requirement for private research is a large and growing demand for agricultural products so that farm-

Table A-14—Regulations on use of pesticides, seeds, and genetically engineered plants, Asia, 1997-98

Country	Pesticides	Seeds	Genetically engineered plants
China	Relatively quick ecological tests, health/safety tests based on foreign data, time reduced in recent years, and data not secret.	Mandatory variety testing and seed registration.	1997 testing protocol established, although use of genetically engineered crops has been growing since the early 1990s.
India	Field testing takes several years and have to duplicate tests done elsewhere, and data not secret. Years required recently declined.	Voluntary variety testing and seed registration.	Field testing since 1996.
Malaysia	Strictly follows WHO/Food and Agriculture Organization guidelines. Banned dirty dozen and pushing integrated pest management (IPM).	Mandatory variety testing and seed registration.	Field testing protocol, but no field tests yet.
Thailand	Quick registration based mainly on foreign data.	Voluntary variety testing and seed registration.	Field tests since 1994.
Indonesia	Banned dirty dozen, pushing IPM for rice.	Mandatory variety testing and seed registration.	No field testing protocol.
Philippines	Relatively quick ecological tests, health/safety tests based on foreign data, data is kept secret, and banning dirty dozen.	Mandatory variety testing and seed registration.	Field testing protocol in 1998. First tests scheduled for 1999.
Pakistan		Mandatory variety testing and seed registration.	

ers demand modern and improved inputs. Traditional agriculture or agriculture which does not have effective demand for modern inputs because infrastructure is inadequate or because policies discriminate against the agricultural sector will not attract private research. Public investments in research and a means of supplying inputs to farmers will be required in countries where land rather than labor is the key constraint to production and locally appropriate modern technology is not readily available. In small countries or niche markets, private research may not develop or supply the needed technology, and public research will continue to be needed to provide technology.

The second requirement is that private firms be allowed to supply agricultural inputs and operate plantations in a competitive market. Obviously, if there is a state monopoly on input supply or if governments run the plantations and food business, private investment will not grow. If public monopolies of input supply are turned into private monopolies, welfare losses are likely to increase. Allowing foreign investment and trade in the input industry is an important way of increasing competition and increasing a country's access to technology that has been developed and commercialized elsewhere in the world. Other needed policies are competition policies that ensure that no local or foreign firm has too much market power.

When these conditions are in place, intellectual property rights and regulatory frameworks can be an important stimulus to private research. With IPR protection, firms will have the ability to capture some of the benefits from research even in competitive markets. Firms will then choose to invest in developing improved inputs or management practices for which there is potential demand and technology opportunities based on local public and private research or research conducted elsewhere.

Finally, with intellectual property rights in place, tax subsidies for research or research parks may be important inducements to further research. R&D tax credits are being tried in a number of places in Asia, although the evidence on their records is mixed. The success of some of the science parks in Taiwan and in industrialized countries demonstrates their potential. But these science parks are typically most successful when they are near major research universities or research institutes that supply ideas for new firms as well as scientists and technicians for the firms. The synergistic relationship between the private science parks and public institutions re-emphasizes the importance of public research, especially on generic problems of industries rather than applied research that provides competing technology.

Competition in Input Industries

Continued policy reform to increase competition in the input industries in Asian countries is an important step.

China still greatly restricts the role of the local private sector and would likely benefit by moving its state-owned enterprises closer to being private firms. That observation is especially true for the seed industry, as the government still has a monopoly on hybrid seed sales.

Reductions in nontariff and tariff barriers by India and China against foreign competition in the input industries would aid the transfer of technology. China not only restricts finished inputs but also restricts foreign firms to 20 percent of the pesticide industry and has official regulations that do not allow foreign firms to own a majority of shares in seed firms. India recently allowed foreign firms to produce pesticides, seeds, and machines for local sale but does not allow imports of any finished agricultural inputs, whether of seed, pesticide, tractors, or irrigation pumps. China is under some pressure to liberalize agricultural input markets as a condition for joining the World Trade Organization (WTO). India is also under pressure from the WTO because it is already a member and has actions pending against it for its nontariff barriers.

Antimonopoly or competitive policies may be important in most advanced developing countries such as Thailand, where the public sector plays a minor role in supplying inputs. In some countries, antimonopoly policy may become important if mergers and acquisitions in the input industries give too much market share to one company. For example, if Cargill combines with DeKalb/Charoen Pokphand, the merger will control up to two-thirds of the hybrid corn seed market in Thailand.

Intellectual Property Rights for Agricultural Inventions

India's and Pakistan's intellectual property laws are not consistent with the Trade Related aspects of Intellectual Property Rights (TRIPS) agreement of the WTO, and all countries in this study except Malaysia (which already has well-respected IPR laws), could use stronger and more effective enforcement. In countries where sufficient IPR laws are already established, the industries will often need to push for better enforcement.

Public Research To Complement Private Research

Enhanced public research support can advance each stage in the research and development process: In traditional agricultural systems, public research can jump-start the agricultural development process and create new markets for modern inputs. Further, public research extends the set of technological opportunities available for private R&D. Public research is also important for conducting the public goods research on environmental and health issues, and working on orphan crops and neglected regions.

Excessive privatization of funding of public research may have the unintended effect of reducing funding for the public sector and the incentive to do public goods research.

Rational Regulatory Regimes

1. Consistent protocols for field testing and commercialization of genetically modified plants and animals among countries would enable better exchange of information between countries for monitoring and enforcement. Public-sector costs for biotechnology regulation can be charged to input companies, as in the case of pesticide regulation.
2. Shared new crop variety testing protocols among countries could help eliminate requirements for mandatory testing and registration of new crop varieties that exist with China and Indonesia and could,

hence, increase the rate of delivery of new private varieties to farmers.

3. To assure that quality inputs are delivered to farmers, countries could strengthen enforcement of truth-in-labeling laws.

Emphasis on Technology Transfer for Small Countries

Openness of borders to international supplies of agricultural inputs can be supplemented by activities, such as providing a network of locations for testing new technology that would reduce firms' costs of bringing in new technology.

Implications of International Technology Transfer for U.S. Policies

The increased rate of international technology transfer has important implications for U.S. farmers, agricultural input industries, and consumers. In this section, we examine some of the implications for U.S. policies toward trade, development, and public agricultural research. But first, we discuss the general question of how agricultural productivity growth in developing countries affects U.S. farmers, industries, and consumers.

Effects of Technology Transfer on U.S. Farmers, Industries, and Consumers

Growth in agricultural productivity is becoming increasingly important for countries to maintain or enhance their competitiveness in the global economy. New technology that lowers unit costs of production makes it easier for producers to export their commodities or compete against imports from other countries. However, there are compelling reasons for maintaining a relatively open environment for international technology flows. In addition to enhancing markets for agricultural input industries and providing consumers with cheaper and more varied products, promoting the international exchange of agricultural technology can yield significant benefits to U.S. agricultural producers.

The first point to recognize is that international technology transfer increases U.S. agricultural productivity. Although the United States is a net exporter of agricultural technology, foreign technology has made major contributions to the productivity of U.S. agriculture and is becoming an increasingly important source of new technology for U.S. producers (Pray and Fuglie, 1999). For example, the ability of the U.S. agricultural research system to provide new and improved crop varieties and livestock breeds relies to a significant degree on access to foreign crop and livestock germplasm. Pardey et al. (1996) estimated that wheat and rice germplasm obtained from the International Agricultural Research Centers added between $3.4 billion and $14.7 billion to the value of U.S. agricultural production between 1970 and 1993, compared with a U.S. contribution of only $134 million to these centers since 1960. Private international technology transfer has also made significant contributions to U.S. agriculture. For example, PIC, based in the United Kingdom and now the market leader in swine genetics in the United States, supplies hybrid swine breeds that incorporate the exceptionally high fecundity of Chinese parent lines and the leanness of European parent lines.

At the same time, international technology transfer does increase the productivity of agricultural producers in other countries. Foreign producers can make new farming methods and improved inputs to raise their productivity and reduce production costs. For U.S. agricultural seed, chemical, and machinery industries, this means new and expanded market opportunities. For U.S. consumers, this implies reduced costs of imported food and food products. For U.S. farmers, some commodity groups may be adversely affected by increased foreign competition or reduced demand for imports, at least in the short run.

The net effect of foreign productivity growth on the U.S. economy is usually measured by how it affects the international terms of trade. The terms of trade is simply the ratio of export prices to import prices. If foreign productivity growth reduces the price of goods imported by the United States (i.e., causes the terms of trade to rise), then the United States could purchase more from abroad with the same level of exports. Thus, foreign productivity growth that caused the terms of trade to increase would provide a net gain in U.S. economic welfare. Productivity growth in imported tropical fruits and beverages that lowered the prices of these commodities, for example, would enhance U.S. terms of trade because fewer U.S. exports would be required to pay for them. On the other hand, productivity growth in commodities that compete with U.S. farm export commodities, such as corn, wheat, and soybeans, could adversely affect U.S. terms of trade by reducing world prices for these goods.

Some studies have suggested that agricultural productivity growth in developing countries, even if it may have shortrun negative effects on U.S. terms of trade, can have positive effects in the long run (see Pinstrup-Anderson, Lundberg, and Garret, 1995 and the collection of studies in Vocke, 1990). This is due to: (1) the importance of the agricultural sector in these countries, so that the rate of growth in the agricultural sector required for growth in the overall economy, and (2) the large share of household incomes spent on food in poor countries, so that an increase in the rate of economic growth translates into a rapid rise in the demand for food. As incomes rise and food consumption turns away from food staples to include more high-valued meat and other products, these countries often increase their imports of agricultural commodities such as meats and feed grains. According to this view, efforts to increase the rate of agricultural technology transfer should not harm U.S. farmers, but can instead enhance markets for U.S. agricultural exports. Agricultural productivity growth in industrialized countries, however, would not have a potentially positive longrun effect on the demand for U.S. agricultural products. In industrialized countries, the size of the agricultural sector is relatively small, and food is a small share of household expenditures. Thus, agricultural productivity growth in these countries will have only a small effect on the economy as a whole and only a small share of increased per capita income will be spent on food.

The empirical evidence on the relationship between agricultural productivity growth and demand for agricultural imports in developing countries is mixed and may have weakened over time (Paarlberg, 1986). One reason is that economic growth and the demand for food imports by developing countries is more strongly influenced by macroeconomic variables, such as interest rates and exchange rates, than by the performance of individual sectors. Another reason is that the emergence over the past decades of international private capital markets to finance economic development has weakened the necessity for agricultural growth to generate overall economic growth in developing countries.

Implications for U.S. Trade and Development Policies

The trade policies endorsed by the United States generally have supported technology transfers to developing countries and greater U.S. food exports. The U.S. Government has supported reductions in agricultural trade barriers through multilateral trade negotiations under the auspices of the World Trade Organization (formerly GATT). Reduced restrictions on trade and foreign direct investment increase the profitability of international technology transfer by multinational agribusiness firms. Further, the United States has sought and obtained commitments to stronger legal protection for intellectual property in these multilateral trading agreements. Stronger intellectual property rights (IPRs) will encourage more private agricultural research and technology transfer, especially in countries that have established the right prerequisites, such as competition in input industries (see the earlier discussion on “Sequencing of Policies”). Most of the effect of these changes will be on developing countries because they have the most trade and investment restrictions and weakest IPRs, especially the developing countries in transition from communism.

Reducing barriers to agricultural input trade and foreign investment in agricultural input industries could have particularly high payoffs in Asian agriculture.

U.S. development policy has provided support for international and national agricultural research systems in developing countries since the 1950s. While the primary aim of these investments has been to increase food production in poor countries, international agricultural research has also provided significant spillover benefits to U.S. agricultural producers. The U.S. Agency for International Development (USAID) has also had a small program to enhance private-sector technology transfer from U.S. agricultural input firms to private companies in developing countries, particularly in biotechnology. However, overall USAID support for technical assistance for agriculture has fallen considerably in real dollars in the past several years.

Continued support of the International Agricultural Research Centers (IARCs) is a key element for maintaining research and economic growth. Funding IARC also helps direct the attention of private biotechnology firms to developing-country opportunities in food and agriculture.

Implications for U.S. Agricultural Research Policy

The main implication of increased speed of international technology transfer is that there are far-reaching benefits from U.S. involvement in collaborative research with other countries and collaborative funding of international agricultural research. Because the benefits of agricultural research, especially research in basic agricultural science, spread to many countries so quickly, research policy needs to find ways to encourage other countries that benefit to pay some of the research costs. Otherwise, a free-rider problem may develop in which no country wants to pay the costs of research, relying instead on technology developed and paid for elsewhere. Spillover benefits from U.S. public research may go to foreign farmers who adopt the technology early, food processors, and consumers of agricultural products.

There are at least three ways to increase cost sharing of this research. The first option is to encourage joint government funding of basic agricultural research. Funding could be shared according to the likely share of benefits received by each country. The actual research could be done collaboratively between institutes in the funding countries, at international agricultural research centers, or by individual national institutes selected on the basis of a competitive grants program. A second option is to develop a public-private international research consortium in which multinational firms fund agricultural research at public universities or national research institutes on generic research that is important to firms but they cannot afford to do by themselves. A third option is to charge multinational firms higher royalties or higher fees for contract research when that research will primarily benefit foreign farmers or consumers. This requires public universities and national research institutes to invest more resources in enforcing their intellectual property rights (which some are already beginning to do) and assessing the foreign markets for their technology.

Increased international collaboration in public agricultural research is already taking place in genome mapping of major food crops. In addition to sharing the costs of basic research, collaboration with agricultural research institutes in developing countries can improve the efficiency of research spending. The costs of research can be reduced by allocating research activities to countries with a comparative advantage in that activity. For example, collaboration can be built on U.S. strengths in basic biological research and the comparative advantage of developing countries in labor-intensive research activities. For example, activities such as plant or poultry breeding that hire large numbers of well-trained workers could be carried out in countries in which labor is relatively inexpensive. Collaboration could also combine the elite germplasm developed in industrialized countries with unimproved germplasm from developing countries to produce hybrids adapted to each area. Collaboration between U.S. public research institutes and the international agricultural research centers has already proven to be extremely useful to U.S. farmers, and continued success can be anticipated.

Future Research Topics on Private Agricultural Research

A number of questions need to be answered before policymakers in the developed or developing countries can be assured that they have developed an appropriate science and technology policy for agriculture. These questions include the following:

> *What is the relative importance of the developing countries' policies and institutions on firms' investments in private research and the distribution of benefits from that research?*

Quantitative studies are needed to determine the effect of policies in industrialized countries on private research in those countries. When studies of private research in Latin America are completed by the International Food Policy Research Institute and International Service for National Agricultural Research, it may be possible to combine their data with results from this effort for some quantitative studies. In addition, it may be possible to obtain indicators of research and technology transfer in specific industries such as biotechnology, which could be used in quantitative studies.

> *What is the effect of private research and technology transfer on farmers and consumers?*

The only quantitative studies on the effect of private agricultural research in developing countries are in India. More studies are necessary for a more reasoned debate on the role of the private sector in agricultural research and its contribution to economic growth.

> *Can the Consultative Group on International Agricultural Research (CGIAR) institutes play a larger role in stimulating private research and the transfer of technology developed by the private sector?*

Much biotechnology is being developed by the private sector in developed countries. The CGIAR is exploring ways of working with the private sector, but even tentative moves in that direction are criticized vigorously by nongovernmental organizations. But whether the CGIAR can help to ensure competition in the international seed and biotech industry has yet to be demonstrated.

Have the donors and development banks developed some successful investments and policies to stimulate private research?

The developed countries have been talking about the importance of private research for some time. But they have yet to demonstrate any successful projects that have stimulated private research to oppose the argument that private research develops naturally when markets are liberalized.

References

Alston, Julian M., George W. Norton, and Philip G. Pardey. *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Ithaca, NY: Cornell University Press. 1995.

Alston, Julian M., Philip G. Pardey, and Johanes Roseboom. "Financing Agricultural Research: International Investment Patterns and Policy Perspective," *World Development*. Vol. 26. 1998. pp.1,057-1,071.

David, C.C., and K. Otsuka (eds.). *Modern Rice Technology and Income Distribution in Asia.* Boulder, CO: Lynne Rienner Publishers. 1994.

Echeverria, Ruben G.. "Impact of Research and Seed Trade on Research Productivity," *Agricultural Research Policy: International Quantitative Perspectives*. Philip Pardey, Johannes Roseboom, and Jock R. Anderson (eds.). Cambridge: Cambridge University Press. 1991. pp. 365-395.

Echeverria, Ruben G., E.J. Trigo, and Derek Byerlee. "Institutional Change and Effective Financing of Agricultural Research in Latin America," World Bank Technical Paper No. 330. World Bank: Washington, DC. 1996.

Evenson, Robert E., Carl E. Pray, and Mark Rosegrant. *Agricultural Research and Productivity Growth in India*. Washington, DC: International Food Policy Research Institute.1999.

Evenson, Robert E., and Larry E. Westphal. "Technological Change and Technology Strategy," *Handbook of Development Economics, Volume III.* J. Behrman and T.N. Srinivasan (eds.). Elsevier Science. 1995. pp. 2,209-2,299.

Evenson, Robert E., and Yoav Kislev. *Agricultural Research and Productivity*. New Haven, CT: Yale University Press. 1975.

Falconi, Cesar. *Public and Private Sector Interactions in Agricultural Research in Less-Developed Countries: The Case of Ecuador*. Discussion Paper 92-13. The Hague, Netherlands: International Service for National Agricultural Research. 1992.

___________. *Public and Private Sector Interactions in Agricultural Research in Less-Developed Countries: The Case of Colombia*. Discussion Paper 93-14. The Hague, Netherlands: International Service for National Agricultural Research. 1993.

Food and Agriculture Organization of the United Nations. Statistical databases. http://apps.fao.org/cgi-bin/nph-db.pl

Fuglie, Keith O., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee. *Agricultural Research and Development: Public and Private Investments Under Alternative Markets and Institutions*. AER-735. U.S. Department of Agriculture, Economic Research Service. May 1996.

Gisselquist, David, and Carl E. Pray. *Deregulating Technology Transfer in Agriculture: Reform's Impact on Turkey in the 1980s.* Policy Research Working Paper 2086. World Bank: Washington, DC. March 1999.

Griliches, Zvi. "Hybrid Corn: An Exploration in the Economics of Technological Change," *Econometrics.* Vol. 25. October 1957. pp. 501-522.

Henry, R., and G. Rothwell. "The World Poultry Industry," *International Finance Corporation Global Agribusiness Series*. Washington, DC: World Bank. 1995.

Mansfield, Edwin. "Intellectual Property Protection, Foreign Direct Investment, and Technology Transfer." Discussion Paper 19, International Finance Corporation. World Bank: Washington, DC. 1994.

Narrod, Clare, and Carl E. Pray. "Technology Transfer in the Poultry Industry: Factors and Externalities Associated with Increased Production," *Animal Wastes and the Land-Water Interface.* Kenneth Steele (ed.). Boca Raton, Florida: CRC Press. 1995. pp. 523-532.

Narrod, Clare, Carl E. Pray, and Willis Peterson. "Technology, Policies, and the Global Poultry Revolution." Unpublished paper. 1999.

Paarlberg, Robert L. "Farm Development in Poor Countries: The Disputed Consequences for U.S. Farm Trade," *American Journal of Agricultural Economics.* Vol. 68. December 1986. pp. 1,353-1,357.

Pardey, Philip G., Julian M. Alston, J.E. Christian, and Shenggen Fan. *Hidden Harvest: U.S. Benefits From International Research Aid.* Food Policy Report, International Food Policy Research Institute, Washington, DC. 1996.

Pingali, Prabhu, M. Hossain, and R.V. Gerpacio. *Asian Rice Bowls: The Returning Crisis?* Wallingford, United Kingdom: CAB International. 1997.

Pinstrup-Andersen, Per, M. Lundberg, and J.L. Garrett. *Foreign Assistance to Agriculture: A Win-Win Proposition*. Food Policy Report, International Food Policy Research Institute, Washington, DC. June 1995.

Pray, Carl E. *Private Sector Research and Technology Transfer in Asian Agriculture: Report on Phase I AID Grant OTR-0091-G-SS-4194-00.* Bulletin 85-5. Economic Development Center, University of Minnesota. December 1985.

Pray, Carl E. *Private Sector Research and Technology Transfer in LDCs: Report on Phase II.* Bulletin 87-1. Economic Development Center, University of Minnesota. March 1987.

Pray, Carl E., Bharat Ramaswami, and Tim Kelley. "Liberalization, Private Plant Breeding and Farmers' Yields in the Semi-Arid Tropics of India." Unpublished paper. World Bank: Washington, DC. April 1998.

Pray, Carl E., and Keith O. Fuglie. "The Private Sector and International Transfer of Agricultural Technology," *Public-Private Collaboration in Agricultural Research.* K. Fugli and D. Schimmelpfennig (eds.). Ames: Iowa State University Press. 2000. pp. 269-299.

Pray, Carl E., and Ruben G. Echeverria. "Determinants and Scope of Private Sector Agricultural Research in Developing Countries," *Agricultural Research Policy: International Quantitative Perspectives.* Philip Pardey, Johannes Roseboom, and Jock R. Anderson (eds.). Cambridge: Cambridge University Press. 1991. pp. 343-364.

Pray, Carl E., Scott Rozelle, and Jikun Huang. "Incomplete Commercialization of the Chinese Seed Industry: The Need For Further Reform." Paper presented at the Global Agricultural Science Policy For the Twenty-First Century conference. Melbourne, Australia. August 29, 1996.

Pray, Carl E., Sharmila Ribeiro, Rolf A.E. Mueller, and P. Parthasarathy Rao. "Private Research and Public Benefit: The Private Seed Industry for Sorghum and Pearl Millet in India," *Research Policy*. Vol. 20. 1991. pp. 315-324.

Ribeiro, Sharmila. "Private Research, Social Benefits and Public Policy: The Case of Hybrid Sorghum and Pearl Millet in the Indian Seed Industry." M.S. thesis. Department of Agricultural Economics, Rutgers University, New Brunswick, NJ. 1998.

Scherer, F.M. *Industrial Market Structure and Economic Performance*. Boston: Houghton Mifflin Company. 1980.

Schumpeter, Joseph A. *Capitalism, Socialism, and Democracy*. Third edition. New York: Harper and Row. 1950.

Thirtle, Colin, and Ruben G. Echeverria. "Privatization and the Roles of Public and Private Institutions in Agricultural Research in Sub-Saharan Africa," *Food Policy.* Vol. 19, No. 1. 1994. pp. 31-44.

Vocke, G. (ed.). *Trade and Development: Impact of Foreign Aid on U.S. Agriculture.* AGES 9004, U.S. Department of Agriculture, Economic Research Service. June 1990.

World Bank. *World Development Report.* New York: Oxford University Press. 1987 and 1997.

List of Tables and Figures